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全国高等院校医学英文版规划教材

供医学类专业留学生及双语教学使用

A Textbook for Medical Students

BIOCHEMISTRY

生物化学

2nd edition

英文版

第 2 版

Chief editors（主 编）
Zhao Baochang（赵宝昌）
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内 容 简 介

本书是我国高等医学院校本科在华留学生和中、英双语教学的生物化学教科书,内容为医学专业类学生应该掌握的基础生物化学与分子生物学理论、基本知识和基本技能,同时也兼顾国家医师执业考试的要求。全书23章,内容分三个板块,分别包括蛋白质、核酸、维生素、酶和糖复合物的结构与功能;糖、脂、氨基酸、核苷酸和矿物质的代谢,以及生物氧化、血液和肝脏的代谢特点和代谢的整合与调节;DNA、RNA和蛋白质的生物合成、DNA损伤与修复、DNA技术、基因组学与蛋白质组学等组学,以及细胞信号转导和癌基因、肿瘤抑制基因和生长因子。全书共有插图342幅,表格67个。为了更好适应医学教学改革的需要,彰显医学生用生物化学教科书的医学专业特色,本书第二版增添了生物化学与医学联系的知识框70个,在分子水平上对某些临床医学现象进行解读。本书还特别注重在华留学生和双语教学的需要,重要的英文专业名词和术语均在其后标有相应的中文,并在书后附有名词释义,对重要的术语给出简洁、准确的概念。各章后均有中、英文对照小结。

本书适用于高等医学院校基础医学、临床医学、预防医学、口腔医学等各专业本科在华留学生和中、英双语教育的学生使用,也可作为从事本专业教师与研究人员的参考用书。

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本书使用说明

随着我国软实力的日益雄厚及国际声誉和地位的不断提升，高等医学教育的国际化视野和需求也愈来愈大，特别是招收来华留学本科医学生和开设双语教学课程的高等医学院校日益增多。为了满足各校对生物化学与分子生物学双语教科书的迫切需要，我们十三所医学院校的生物化学同行合力编写了此教材。本书的适用对象是高等医学院校基础医学、临床医学、预防医学和口腔医学等专业的本科学生，特别是在各高校就读上述专业的来华留学生。本书也可作为从事双语教学教师的一部重要教学参考书。

本书的内容为医学专业学生应该掌握的生物化学与分子生物学基础理论、基本知识和基本技能，同时也兼顾国家执业医师考试的要求。全书共23章，内容包括三部分。第一部分是生物分子的结构与功能，包括蛋白质、核酸、酶、糖复合物和维生素的结构与功能；第二部分是物质代谢、能量代谢及其相关内容，包括糖、脂、氨基酸、核苷酸、矿物质的代谢，以及生物氧化和代谢的整合与调节。本部分还包括血液和肝脏的生物化学特性及其与代谢相关的内容。第三部分包括DNA、RNA和蛋白质的生物合成与加工、DNA的损伤与修复、基因表达的调控。我们把与遗传信息传递相关的重要技术及其应用列为一章，即DNA技术。这将有利于教学的系统性和学生对相关知识的连贯掌握。这部分还包括基因组学与蛋白质组学等组学、细胞信号转导，以及癌基因、肿瘤抑制基因和生长因子的相关知识。各校可根据自身的教学计划和教学习惯，以及与相关学科的衔接关系，可对各章节的内容进行取舍或变更教学流程。

本书为适应我国医学教学改革和教学模式的转变，彰显本教材编写的旨意和医学特性，强化生物化学与分子生物学基本理论与临床医学实践的联系，激发学生学习医学的热情，我们增添了基础理论与临床医学联系的知识框。授课教师可酌情对学生必须掌握的、熟悉的、一般了解的内容加以区分，以引导学生自主学习。

本书还特别考虑到了来华留学生和进行双语教学的师生在教材使用中对中文的需要，对各章节中重要的英文生化专业名词和术语在其后均标有相应的中文，并在书后附有名词释义，对一些重要的术语给出简洁、准确的概念。各章后还附有中、英对照小结。索引与名词释义的术语均采用中、英文对照模式。书中的中文可以激发留学生学习中文的兴趣和积极性，帮助他们逐步掌握中文专业词汇。接受双语教学的中国学生可以借助书中的中文正确地掌握英语专业名词的翻译规律。

我们希望本教材的编写和使用，不但对提高生物化学与分子生物学的双语教学水平有所帮助，也能为推动我国医学教育的国际化做出贡献。由于我们的水平有限，本书难免会有一些不尽人意之处，热切期盼使用本书的同行和学生对本书提出宝贵意见，以便进一步完善。

编　者

2015年9月

Preface

It is our pleasure to present the second edition of *Biochemistry*: *A Textbook for Medical Students* to students in medicine and other medicine related majors. The last edition was published in 2009, and since then it has been reprinted 6 times to meet the need from thousands of medical students from over 20 universities and colleges. We are pleased to see that this book has become serviceable both to the teachers and students.

In the last decade, many omics have advanced our understanding about the life at the molecular level, and uncovering the mysteries of cancer, Alzheimer and other diseases harmful to humans has been growing at an astounding pace. It is the time to revise the textbook. It is our responsibility to introduce new basic concepts in a more accurate manner, to describe the principles more terse, to arrange the contents more logical and to make the reading more enjoyable. It is the first consideration when we rewrite this book. Furthermore, medical education is also undergoing a rapid innovative reformation worldwide, advanced teaching technique and strategies, such as problem - based teaching, case- based teaching, etc. have been executed in every corner around the campuses. The textbook should to adapt to these changes and provide encouragement to assist the students' self- study. It is our second consideration when rewriting this book.

The second edition includes the following new features. All chapters are revised with the inclusion of up- dated contents and corresponding new figures or new tables. A new chapter on "- omics" is added to reflect the growing significance and versatility of these new techniques. All 23 chapters are rearranged into three parts. Part Ⅰ discusses the structures and functions of some major biomolecules including proteins, nucleic acids, vitamins, enzymes and glycoconjugates. Part Ⅱ deals with metabolisms of carbohydrates, lipids, amino acids, nucleotides, the related biological oxidation, minerals, and the integration and regulation of metabolism. In this part, metabolic characteristics of the blood and liver are also described individually. Part Ⅲ describes the flow of the genetic information and its regulation, the major DNA technology and some important omics. Besides, oncogens, tumor suppressors and growth factors, and signaling are also described. Since some contents have been studied in the course of *Cellular Biology*, the chapter *Biomembranes* has been eliminated from this textbook. In the second edition, several demonstrative boxes have been added to introduce briefly the fundamental knowledge about human diseases and to emphasize the significance between biochemistry and medicine.

When writing the second edition, eleven senior professors as the original writers of the first edition are unable to join us due to different reasons. They have contributed their precious experience, intelligence and wisdom to this textbook. We want to express our sincere respects to them. Now, several new colleagues from different universities are participating in writing the new edition, their energetic and enthusiastic spirit will facilitate our colleagues' teaching as well as students' learning.

The authors thank Taishan Medical College for successfully organizing the compilation meeting. We are grateful to Li Guohong, the president of High Medical Education Branch of Science Press, and Zhu Hua, the editor for their enthusiastic supports and friendly help. We also express our heartfelt thanks to our colleagues and lovely students for their suggestions and comments in the past seven years, which are significantly helpful for us to write the second edition. We look forward to continuing to receive your creative suggestions and comments in the future.

Zhao Baochang
Guan Yifu
Yan Qiu
Gao Xu
Wang Minghua
Zhai Jing
October 2015, Dalian, China

Contents

Introduction

Life is one of the motional modes of matters. Thousands of different lifeless and lives on the Earth are made from the simple elements and compounds. The remarkable common properties of living organisms distinguishing from nonliving materials are the capacity for precise self-renewal (metabolism), and self-replication and self-assembly (expression and transmission of genetic information), although they maintain and perpetuate themselves to conform to all the physical and chemical laws that govern the nonliving universe. Biochemistry is the chemistry of life, the aim is to describe and explain, in molecular terms, all chemical processes in living cells.

Biochemistry seeks to explain life at the molecular level, its knowledge is essential to all life sciences. Biochemistry of nucleic acids locates at the heart of genetics.Biochemistry overlaps with physiology, the study of body functions. Pharmacology, pharmacy, and toxicology lie on the basic knowledge of biochemistry; in particular, most drugs and poisons rely on the biochemical processes for their function and are metabolized and biotransformed by enzymatic reactions. Most subjects of life sciences employ biochemical approaches almost exclusively to break down their technical barriers and biochemical theory to explain various phenomena at molecular levels. Biochemistry is increasingly becoming the common language of those subjects.

The reciprocal relationship between biochemistry and medicine has promoted their mutual advances. The normal biochemical processes are the basis of body health, and all diseases have a biochemical basis. Biochemical studies have been enormously accelerating the development of the understanding of both health maintenance and effective treatment of diseases. The study of various aspects of medicine has been opening up new areas of biochemistry.

The achievements of biochemical investigation catalyze the birth of several new disciplines. Bioinformatics, for example, represents a new growing area of science that employs computational approaches to answer biological questions, and efficiently guides experimental design in laboratories.

Biochemistry describes the following contents.

1. The field of study on chemical constituents of living organisms and the structures and functions of biomolecules is termed to as "Static Biochemistry (静态生物化学, 叙述生物化学)". As it is known that about 30 of the more than 90 naturally occurring chemical elements are essential to the living organisms, and most of the 30 elements are lighter elements including the four most abundant elements: hydrogen, oxygen, nitrogen, and carbon, which together make up more than 99% of the mass of most cells and construct the main part of biomolecules. Other elements including trace elements also play very important roles in many aspects. The organic compounds, which constitute humane body and/or play important roles for maintaining normal living activities, are named biomolecules.

Proteins, nucleic acids, and polysaccharides with the molecular weight of mostly more than 10 000Da are termed to as biomacromolecules (生物大分子) which are polymers constructed by their own basic units. Proteins consist of hundreds to thousands of linked amino acid residues by peptide bonds; nucleotides and deoxynucleotides linked by 3′, 5′-phosphodiester bonds are the basic units of RNA and DNA, respectively. Most enzymes are proteins with catalytic activities. The primary structure of biomacromolecule determines its spatial structures, and the latter is the basis of their functions. The structure and function of proteins are the material bases and embodiment of living activities; nucleic acids store and transmit genetic information. The normal structure and function of these macromolecules are essential for maintenance of body under control.

Vitamins are a group of low-molecular organic compounds essentially from diet. Though neither for body structure nor for energy supply, vitamins are essential for maintaining physiological functions of promoting growth and regulating metabolism.

2. Metabolism and its regulation are referred to as Dynamic Biochemistry (动态生物化学). Living organisms have the ability to construct and renew themselves by extracting and digesting nutrients from and excreting the end products to their environment. Many consecutive chemical reactions catalyzed by a series of enzymes responsible for a given function constitute metabolic pathways. Metabolism is the sum of all the chemical reactions or the net of pathways taking place in a cell or organism. Metabolism, one of the very important characteristics of life, can be divided into two major categories: catabolism (degradation) and anabolism (biosynthesis). The energy required by anabolism (an endergonic process) is provided by catabolism (exergonic process). Metabolic pathways are regulated at several levels. The regulation of enzymes is the essential models for controlling the metabolism in balance. Cellular signal transduction is involved in the metabolism and deals with the growth, proliferation, differentiation and other living processes of the body. The disorder of metabolism may cause various diseases.

3. Self-replication and transmission of genetic informations are the other basic characteristics of living organ-

isms. As the repository of the genetic information, DNA is the most material basis of the heredity, while genes are the functional segments of DNA. The central dogma of molecular biology comprises the three major processes in the cellular utilization of genetic information: replication, transcription, and translation. Reverse transcription is a profitable replenishment of the dogma. The expression of genes is strictly regulated at many points. The study on the storage, expression, and transmission of genetic information has a very important standing in the field of biochemistry and molecular biology, since the transmission of genetic information involves heredity, variation, growth, proliferation, differentiation, and so on, and deals with the pathogenesis of genetic disorders, malignant tumors, cardiovascular diseases, etc.

Cells have the ability to respond the surrounding signals, which are detected by specific receptors and converted to a cellular response. Signal transduction is a universal property of living cells. Many signal transductive pathways constitute crosstalk to control growth, proliferation, differentiation, and aging of the living organisms. Any abnormality of either the transmission and regulation of genetic information or the signal transduction can cause various diseases.

In a broad sense, molecular biology is defined as the study of the structures and functions of biomacromolecules including proteins, nucleic acids, enzymes, glycoconjugates. In a narrow sense, it is focused on the storage, transmission and controlling of genetic information. DNA technology, genomics and other omics include in this field.

4. For medical students, the biochemistry of tissues and organs is quite important. This discipline can be called "Functional Biochemistry (功能生物化学)". In addition to the common types of metabolic pathways, organs or tissues have their own metabolic patterns for their distinguish functions. It is very important for medical students to get the knowledge of some medically important organs and tissues such as the liver, blood, and so on. The liver locates in the center of carbohydrate, lipid, and protein metabolism, and also metabolizes xenobiotics (异源物) and bile pigments. The liver is also the largest exocrine organ for excreting bile acids and other metabolites. Impaired liver function compromises many metabolic processes leading to serious pathology. Blood circulation is the traffic line for nutrients, metabolites, regulators, end products, as well as oxygen and carbon dioxide. Blood circulation connects tissues and organs for crosstalking. Plasma components and blood cells are important for carrying out their specific functions. Blood samples can provide critical information about body functions and help physicians to diagnose many diseases.

The modern biochemistry is a young but fast growing field of investigation. The term "biochemistry" seems to be first used in 1882, it was generally accepted in 1903. In the 19^{th} and early 20^{th} centuries biochemistry dealt more with extracellular chemistry, such as the discovery of glycerol, citrate, malate, lactate and uric acid, the chemistry of digestion and of body fluids. When the history stepped into 20^{th} century, the course of research turned from State Biochemistry to Dynamic Biochemistry. In the first fifty year period of the 20^{th} century, biochemistry discussed more with the constituents of the body, metabolism and its regulation, and biochemical nutrition. The research achievements about the structures and functions of vitamins, coenzymes and hormones, the kinetics of enzymatic reactions, metabolic pathways of carbohydrate, β-oxidation of fatty acids, ornithine cycle and citric acid cycle, and so on were the major contributions in this period. The basic framework of biochemistry was established.

Since the middle of 20^{th} century, biochemistry was growing fast to a golden age, and ushered in a new era of molecular biology. This was epitomized by the discovery of the double-helical structure of DNA, postulated by James Watson and Francis Crick in 1953. Recombinant DNA technology paved the way to the modern field of genomics and proteomics, the study of genes and proteins on the scale of whole cells and organisms. The development of practical DNA sequencing methods inspired the confidence in scientists for the studies on genomics of different species, including sequencing the entire 3 billion base pairs of the human genome. The Human Genome Project started in 1990, and the completed sequence of the human genome was published in April 2003. The effort eventually included significant contributions from 20 sequencing centers in six nations: the United States, Great Britain, Japan, France, China, and Germany. Human Genome Project marked the culmination of 20^{th} century biology, and promised a vastly changed scientific landscape for the new century. The artificially alterations of genome from animals or plants by biotechnology may produce new species. Detection of individual genome can facilitate the diagnosis of some diseases, and to design the strategy of gene therapy. Recombinant DNA technology can yield new products and challenges, discover new pharmaceuticals.

With the deepening of the research on genomics, post-genomics era has been placed on the agenda. The investigation on proteome, the complement of proteins expressed by a genome is called proteomics, including the localization, relationships of structure and function, and interactions of proteins, as well as the temporal and spatial specificities of expressional profiles of proteins. Transcriptomics is defined as an investigation on entire mRNA expressed in organism and its responses to environmental changes. In fact, the biological functions of RNAs are far more than the transmission of genetic information. Besides mRNA, tRNA, and rRNA, another group of small non-messenger RNAs (snmRNAs)incorporates the regulation of gene expression and so on. The investigation focusing on the types, structures and functions of snmRNAs, and their temporal and spatial specificities of expressional profiles in the same and different cells is termed RNomics. Metabonomics is a concept that has been defined as the understandings of the comprehensive monitoring of the metabolic complement in organism and its responses to environmental changes including the development of individual diseases and effects of medicines, as well as the investigation of finding biomarkers and fingerprinting of diseases. Glycomics is the investigation on the structure and function of glycans. Achievements in these investigations inevitably arouse revolutionary changes in many fields. Once the mystery of the nature of life is uncovered, it will give much great influences on the understanding of nature of life, pathogenesis, prevention, and therapy of diseases, anti-aging, and development of new medicines and so on.

(Zhao Baochang)

Chapter 1 Structures and Functions of Proteins

OUTLINE

Proteins (蛋白质) are macromolecules built of amino acids as constituents of monomer. Thousands of different kinds of proteins constitute over 50% of the dry weight of cells, performing multiple critically important roles in all biological processes. Proteins serve as matrix for bone and connective tissues, giving structural forms to the living organisms, and as cytoskeleton maintaining cellular shape and physical integrity. Actin and myosin are the major constituents of contractile machinery of muscles. Some proteins transport and store certain important molecules such as oxygen (myoglobin and hemoglobin), iron (transferrin and ferritin), and lipids (lipoproteins). Most enzymes are proteins catalyzing thousands of chemical reactions. Gene replication, transcription and translation, cell proliferation and differentiation are catalyzed by enzymes and also controlled by protein factors. Many hormones and cytokines are proteins or peptides for regulating metabolism; insulin, thyrotropin, growth hormone, growth factors, and interleukins are the examples. Receptors are proteins enabling cells to respond to hormones and other environmental cues. Some proteins, such as immunoglobulins and interferons, can protect the body against bacterial or viral infections. Study of human physiology and pathology requires a thorough understanding of protein structures and functions, which is also the basic knowledge for further study on biochemistry and other disciplines.

1.1 Amino Acid Composition in Proteins

Even though there are a diversity of proteins in the world, the major chemical elements for simple proteins are C (50%−55%), H (6%−7%), O (19%−24%), N (13%−19%), and S (0%−4%). Proteins are the major nitrogen-containing compounds with the nitrogen amount being about 16% of the molecular weight. Accordingly, protein can be quantified by measuring the quantity of its component nitrogen. 1 gram of nitrogen is equal to about 6.25 grams of protein.

Protein amount (g) in a sample = total nitrogen amount (g) in the sample × 6.25

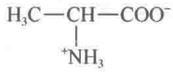
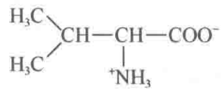
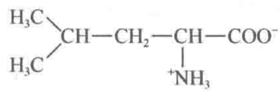
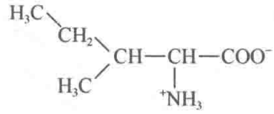
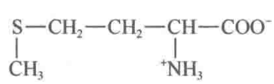
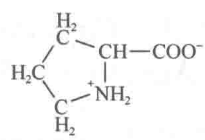
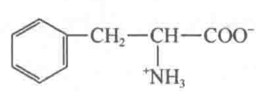
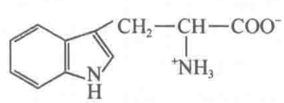
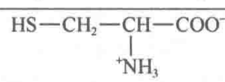
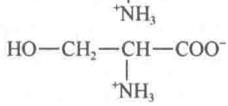
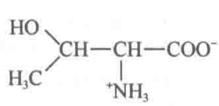
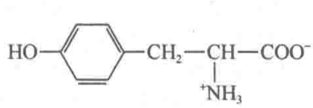
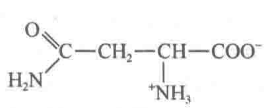
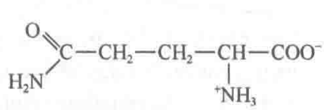
1.1.1 Structure and Classification of Amino Acids

Of the over 300 different naturally occurring amino acids, only 20 types of amino acids constitute different proteins in mammalian organisms. These 20 common amino acids share a common structural feature. All contain a central alpha (α)-carbon atom to which a carboxyl group, an amino group, and a hydrogen atom are covalently linked. In addition, there is a specialized chemical group binding to this α-carbon, which is designated as R group or called side chain in peptides. These structures contribute the features the common amino acids including ① the acid-base properties, ② the capacity to polymerize by forming peptide bonds, ③ varied structure and chemical functionality determined by side chains, ④ chirality of *L*-stereoisomers (with the sole exception of glycine). According to the polarities of R groups, the 20 amino acids can be classified into neutral amino acids, acidic amino acids, and basic amino acids. Amino acids can be represented by three-letter and one-letter abbreviations (Table 1-1).

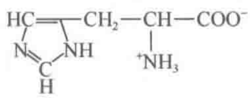
Table 1-1 *L*-α-Amino acids present in proteins

Name and symbol	Structural formula	pK_1 (α-COOH)	pK_2 (α-NH_3^+)	pK_3(R group)	pI
Neutral non-polar amino acids (amino acids with nonpolar aliphatic or aromatic R groups)					
Glycine (Gly, G)	H—CH—COO$^-$ | $^+NH_3$	2.34	9.60	—	5.97

Continued

Name and symbol	Structural formula	pK_1 (α-COOH)	pK_2 ($\alpha\text{-}NH_3^+$)	pK_3(R group)	pI
Alanine (Ala, A)		2.35	9.69	—	6.02
Valine (Val, V)		2.32	9.62	—	5.96
Leucine (Leu, L)		2.36	9.60	—	5.98
Isoleucine (Ile, I)		2.36	9.60	—	6.02
Methionine (Met, M)		2.28	9.21	—	5.74
Proline (Pro, P)		1.99	10.60	—	6.30
Phenylalanine (Phe, F)		1.83	9.13	—	5.48
Tryptophan (Trp, W)		2.83	9.39	—	5.89
Neutral polar amino acids (amino acids with non-ionic polar R groups)					
Cysteine (Cys, C)		1.96	8.18 Thiol	10.28 $\alpha\text{-}NH_3^+$	5.07
Serine (Ser, S)		2.21	9.15	—	5.68
Threonine (Thr, T)		2.09	9.10	—	5.60
Tyrosine (Tyr, Y)		2.20	9.11 $\alpha\text{-}NH_3^+$	10.07 phenolic-OH	5.66
Asparagine (Asn, N)		2.02	8.80	—	5.41
Glutamine (Gln, Q)		2.17	9.13	—	5.65
Acidic amino acids (amino acids with ionic side chains)					

Continued

Name and symbol	Structural formula	pK_1 (α-COOH)	pK_2 (α-NH_3^+)	pK_3(R group)	pI
Aspartic acid (Asp, D)	$HOOC-CH_2-CH(^+NH_3)-COO^-$	1.88	3.65 β-COOH	9.60 α-NH_3^+	2.77
Glutamic acid (Glu, E)	$HOOC-CH_2-CH_2-CH(^+NH_3)-COO^-$	2.19	4.25 γ-COOH	9.67 α-NH_3^+	3.22
Basic amino acids (amino acids with ionic side chains)					
Lysine (Lys, K)	$H_2N-CH_2-CH_2-CH_2-CH_2-CH(^+NH_3)-COO^-$	2.18	8.95 α-NH_3^+	10.53 ε-NH_3^+	9.74
Arginine (Arg, R)	$H_2N-C(=NH)-NH-CH_2-CH_2-CH_2-CH(^+NH_3)-COO^-$	2.17	9.04 α-NH_3^+	12.48 guanidinium	10.76
Histidine (His, H)		1.82	6.00 imidazolium	9.17 α-NH_3^+	7.59

Among the 20 common amino acids, proline is an imino acid with the α-carbon and nitrogen incorporating into a five-membered ring. Some proteins also contain additional amino acids that arise by post-translational modifications of the already present amino acids in the peptides. Examples include 4-hydroxyproline and 5-hydroxylysine in collagen, io-dotyrosine in thyroglobulin, γ-carboxyglutamate in some coagulation factors, and methylated, acetylated, and phosphorylated amino acids in certain proteins. These modifications extend the biologic diversity of proteins.

Selenocysteine (硒半胱氨酸)is a special case. It is introduced during protein biosynthesis rather than created through a post-translational modification. Selenium-containing proteins (selenoproteins, 硒蛋白)are responsible for some special functions (Chapter 13).

In addition, there are some free *L*-α-amino acids in human bodies not as the constituents of proteins, but having very important biological roles, such as ornithine, citrulline, and argininosuccinate, which incorporate in the synthesis of urea (BOX 1-1).

BOX 1-1 Free Amino Acids in Urine

In urine and plasma, there are some amino acids freely or combined, but not in proteins. The measurement of abnormal amino acids in urine is useful for clinical diagnosis. Urinary amino acid concentration is usually at the level of μmol/g creatinine. Creatinine, as a derivative of some amino acids, constantly produces in muscle, keeps relatively constant amounts in plasma and urine. Glycine is the most abundant amino acid in urine with 400 − 2000μg/g creatinine.

1.1.2 Physicochemical Properties of Amino Acids

1.1.2.1 Amphoteric Dissociation and Isoelectric Point of Amino Acids

Besides the basic α-NH_2 and acidic α-COOH, the R groups of some amino acids contain additional—NH_2 (lysine), guanidinium group (arginine), imidazole group (histidine), or —COOH (glutamic acid and aspartic acid). Both —COOH and —NH_3^+ are weak acids; while both —COO^- and —NH_2 are weak bases. Therefore, amino acids are ampholytes (两性电解质)in solution and the ionization state of an amino acid varies with pH. In acidic solution, the amino group is protonated (—NH_3^+)and the carboxyl group is not dissociated (—COOH), the amino acid is positively charged. As the pH rises to basic condition, the —COOH is the first group to release H^+, and then the —NH_3^+ loses H^+, the amino acid is negatively charged. At a certain pH, the amino acid has an equal number of positive and negative charges and thus is electrically neutral. The pH in solution, at which the amino acid bearing no net charge is a dipolar ion (also called zwitterion, 兼性离子), is the isoelectric point (pI, 等电点)of the amino acid. At pI a zwitterion does not migrate in an electric field.

pK_a is termed as the negative logarithm of dissociation constant. The pI is the pH midway between pK_a values on both sides of the isoelectric species. For alanine, the dissociation constants of α-COOH and α-NH_3^+ are 2.35 and 9.69, respectively (Table 1-1), the pI is (2.35 + 9.69) ÷ 2 = 6.02 (Figure 1-1).

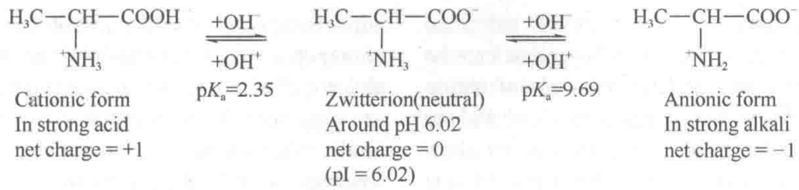


Figure 1-1 Ionic forms of alanine and its isoelectric point

1. 1. 2. 2 Ultraviolet Absorption and Chemical Color Reaction of Amino Acids

Tryptophan and tyrosine absorb ultraviolet light with a maximum absorption at ~ 280nm (Figure 1-2). This characteristic strong absorbance of light at this wavelength by most proteins is exploited by researchers in providing means for spectrophotometric determination of protein concentrations in a solution.

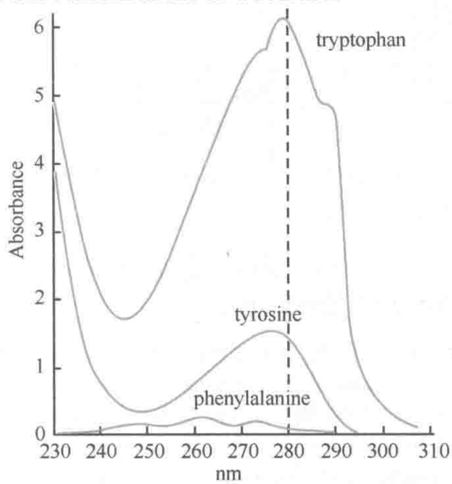


Figure 1-2 Absorption of ultraviolet light by aromatic amino acids

Amino acids can react with ninhydrin (茚三酮), a strong oxidizing agent, to produce CO_2, ammonia, an aldehyde, and a reduced derivative of ninhydrin. The latter then react with the ammonia produced in this way, and another molecule of ninhydrin to yield a blue purple product that can be spectrophotometrically quantified at 570 nm for determination of amino acid concentrations.

1. 2 Molecular Structure of Proteins

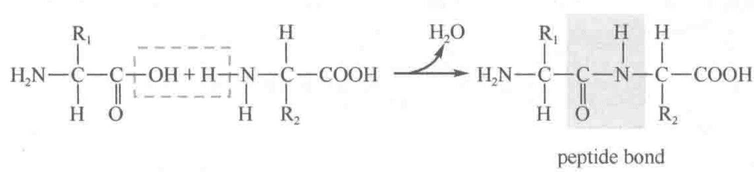
Four levels of protein structure are commonly defined: primary structure, secondary structure, tertiary structure, and quaternary structure.

1. 2. 1 Primary Structure of Proteins

Chemically, proteins are unbranched polymers of amino acids linked from the α-carboxyl group of an α-amino acid to the amino group of another amino acid through formation of covalent amide linkages named peptide bonds (肽键).

1. 2. 1. 1 The Linkage of Amino Acids in Protein Molecules

Two amino acid molecules can be covalently linked together by a peptide bond to yield a dipeptide (二肽). Such a linkage is produced by removal of one H_2O molecule from the α-carboxyl group of one amino acid and the α-amino group of the second amino acid. The dipeptide can further form a second peptide bond by removal of the elements of water from its terminal carboxyl group and the α-amino



group of the third amino acid to generate a tripeptide (三肽). The procedure can be repeated to produce a polypeptide (多肽) with a specific amino acid sequence. In polypeptide, each condensed amino acid is termed amino acid residue (残基). The oligopeptide (寡肽) is designated when a peptide is composed of residues less than 10. Proteins may have hundreds to thousands of amino acid residues. In general, the term of protein is used for molecules composed of over 50 amino acid residues; and polypeptide is used for those less than 50 amino acid residues. But the terms "protein" and "polypeptide" are not precise, and sometimes used interchangeably, a molecule with molecular weight below 10 000 Da may also be re-